EVALUATE FIN PERFORMANCE OF A SPACE RADIATOR TO REMOVE HEAT GENERATED FOR OUTER SPACE APPLICATION

NOR NASHRIQ AZIZI BIN ABD. SHUKOR

Report submitted in fulfillment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

DECEMBER 2010

UNIVERSITI MALAYSIA PAHANG

FACULTY OF MECHANICAL ENGINEERING

I certify that the project entitled "*Evaluate Fin Performance of a Space Radiator to Remove Heat Generated for Outer Space Application*" is written by *Nor Nashriq Azizi Bin Abd. Shukor*. I have examined the final copy of this project and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in partial fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering.

MR. AHMAD BASIRUL SUBHA BIN ALIAS

Examiner Signature

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project report and in my opinion this project report is sufficient in terms of scope and quality for the award of the Bachelor of Mechanical Engineering.

Signature :
Name of Supervisor : PROF. DR. KORADA VISWANATHA SHARMA
Position : LECTURER
Date : 6 DECEMBER 2010

STUDENT'S DECLARATION

I declare that this report titled "*Evaluate Fin Performance of a Space Radiator to Remove Heat Generated for Outer Space Application*" is my result of my own research except as stated in the references. This thesis/report has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature	:
Name	: NOR NASHRIQ AZIZI BIN ABD. SHUKOR
Id. Number	: MA08010
Date	: 6 DECEMBER 2010

ACKNOWLEDGEMENTS

First and foremost, I would like to express my grateful to ALLAH S.W.T. as for the blessing given that I can finish my project.

In preparing this paper, I have engaged with many people in helping me completing this project. First, I wish to express my sincere appreciation to my supervisor, Prof. Dr. Korada Viswanatha Sharma for his germinal ideas, continuous encouragement, invaluable guidance, advices and motivation. Without his continued support and interest, this thesis would not have been the same as presented here.

In particular, my sincere thankful is also extends to all my colleagues and others who have provided assistance at various occasions. Their views and tips are useful indeed. I cannot find the appropriate words that could properly describe my appreciation for their devotion, support and faith in my ability to attain my goals. I would like to acknowledge their comments and suggestions, which was crucial for the successful completion of this study.

Last but not least I acknowledge without endless love and relentless support from my family, I would not have been here. My father, Abd Shukor Bin Lodin, my mother, Rohayah Binti Samad, all my brothers and sisters that always support, sacrifice, patience, understanding that were inevitable to make this work possible, motivation and encourage me to success. I cannot find the appropriate words that could properly describe my appreciation for their devotion, support and faith in my ability to attain my goals.

Thank you all.

ABSTRACT

Heat is generated in spacecrafts due to air-condition system, electronic and electrical equipment, human beings, etc. The heat generated from these sources must be removed in order to maintain the spacecraft at the required temperatures. Heat rejection to outer space is the area of present work where radiation is the dominant single mode. Extended surfaces are advantageous for this situation for heat dissipation to outer space. To simulate conditions of outer space where convection is not present is difficult and costly. Hence convection cannot be excluded in the testing of space radiator. The present analysis includes convection and irradiation terms. The physical situation considered is a horizontal fin with a rectangular cross-section. One end of the fin is maintained at a constant elevated temperature, and the fin is short and the heat loss from the tip is negligible. Heat is transferred by conduction along the fin and dissipated from the surface via natural convection and radiation. The numerical solution is obtained for the present problem by developing an algorithm where the domain is discretized by Taylor series central difference scheme and have been solved by Jacobi method, which possesses the quality of exceptional accuracy with a few numbers of nodes. The algorithm is computed using FORTRAN Software with certain parameter value. This method of approach helps to estimate its performance under actual working conditions. A comparison is made to published results, and the agreement between the present and previous is very good. Results show that the total heat loss to ambient strongly effected by convection and radiation. In the absence of convection, the efficiency is decrease with the increasing of radiation parameter. It is also show that increasing of radiation parameter will increase the total heat transfer to ambient. Longitudinal heat conduction parameter will increase the amount of heat dissipated to ambient. Because of several limiting assumptions, the results would be used only for preliminary analysis and design particularly when a fin assembly is involved rather than an individual fin.

ABSTRAK

Haba didalam kapal angkasa telah dihasilkan oleh sistem penghawa dingin, peralatan elektronik dan elektrik, radiasi dari manusia dan sebagainya. Haba yang agak tinggi ini harus dikeluarkan untuk mengekalkan suhu yang diperlukan oleh kapal angkasa itu sendiri. Penyingkiran haba ke luar angkasa adalah subjek utama didalam kajian ini di mana radiasi adalah satu satunya cara untuk haba disingkirkan dari kapal angkasa. Sirip (permukaan lebihan) telah digunakan untuk meningkatkan penyingkiran haba ke luar angkasa. Untuk mensimulasikan keadaan ruangan luar di mana perolakan haba tidak berlaku adalah sukar dan mahal. Oleh itu, perolakan haba tidak boleh dikecualikan dalam menguji sistem penyejukan kapal angkasa. Analisis yang dilakukan ini merangkumi perolakan dan radiasi. Analisis dilakukan keatas satu sirip berbentuk segi empat. Pangkal sirip ditetapkan pada suhu yang tinggi dan malar dan sirip ini adalah pendek, oleh itu kehilangan haba dari hujungnya boleh diabaikan. Haba dipindahkan oleh konduksi sepanjang sirip dan disingkirkan dari permukaan melalui perolakan dan radiasi. Penyelesaian berangka yang diperolehi untuk analisis ini telah dikembangkan dari sebuah algoritma yang didiskritisasi oleh *Taylor series central difference scheme* dan telah diselesaikan dengan kaedah Jacobi yang persis dengan beberapa nod. Algoritma ini telah dihitung menggunakan perisian FORTRAN dengan beberapa nilai tertentu. Kaedah ini membantu untuk menilai prestasi sistem penyejukan kapal angkasa di angkasa lepas. Perbandingan keputusan analisis dengan keputusan yang telah diterbitkan adalah sangat hamper. Keputusan kajian menunjukkan bahawa haba yang disingkirkan ke persekitaran sangat dipengaruhi oleh perolakan dan radiasi. Ketika ketiadaan perolakan, kecekapan sirip menurun apabila radiasi meningkat. Keputusan juga menunjukan peningkatan radiasi akan meningkatkan jumlah haba yang disingkirkan. Nisbah sirip-cecair akan meningkatkan jumlah haba yang disingkirkan. Disebabkan beberapa permudahan analisis, hasilnya akan digunakan hanya untuk analisis awal terutama pada kombinasi sirip yang banyak.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

q_{cond}	Heat transfer by conduction, $kA_c\Delta T / L$
q_{conv}	Heat transfer by convection, $hA_s\Delta T$
q_{rad}	Heat transfer by radiation, $\sigma\varepsilon(T_s^4 - T_\infty^4)$
q''	Heat Flux
Q_{fin}	Total Energy at Fin
Q_{fluid}	Total Energy in Fluid
T_{out}	Temperature Out From Fin
T_{in}	Temperature In To Fin
T_s	Surface Temperature
T_b	Base Temperature
T_∞	Ambient Temperature
T_f	Fluid Temperature
T_{fi}	Fluid Temperature, in
T_{fo}	Fluid Temperature, out
^oC	Degree Celsius
k	Thermal Conductivity
h	Convection Heat Transfer Coefficient
E	Surface Emissive Power
σ	Stefan-Boltzmann Constant
ε	Emissivity
A	Area
A_C	Cross Sectional Area
A_S	Surface Area

L	Length of Fin
P	Perimeter
H	Length of Tube
G	Irradiation
C_p	Specific heat capacity at constant pressure
m	Mass
Bi	Biot Number, hL_c / k
δ	Thickness of Fin
δ_c	Thickness of Fin at Cold Side
δ_h	Thickness of Fin at Hot Side
N_P	Profile Parameter, δ_c / δ_h
N_R	Radiation Parameter, $[2\varepsilon\sigma L^2(T_b-T_\infty)^3] / k\delta_h$
N_C	Convection Parameter, $h / \sigma\varepsilon(T_b-T_\infty)^3$
N_G	Irradiation Parameter, $\alpha G / \sigma\varepsilon(T_b-T_\infty)^4$
N_F	Longitudinal Heat Conduction Parameter, $2k_p\delta_h H / mc_p L$
θ	Dimensionless Temperature Ratio Term, $(T-T_\infty) / (T_b-T_\infty)$
θ_b	Dimensionless Fluid Temperature, $(T_{fi}-T_{fo}) / (T_{fi}-T_\infty)$
ψ	Dimensionless Temperature Ratio Term, $T_\infty / (T_b-T_\infty)$
ξ	Dimensionless Distance, x / L
x	Distance along the Fin
z	Distance along the Tube

LIST OF ABBREVIATIONS

UMP	Universiti Malaysia Pahang
FKM	Fakulti Kejuruteraan Mekanikal
NASA	National Aeronautics and Space Administration
ISS	International Space Station
ANSI	American National Standards Institute
SI	The International System of Units
FORCE	Fortran Compiler and Editor

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

As against the three modes of heat transfer, viz., conduction, convection and radiation, radiant heat transfer plays a dominant role in space applications. Whereas heat rejection in terrestrial applications is dominantly by convection, it is solely by radiant heat transfer in space systems. The basic difficulty associated with radiation heat transfer is its non-linear dependence on temperature. This non-linearity makes it difficult to analyze, except for simple configurations, by analytical methods.

Space radiators are used for waste heat rejection generated by electronic equipments, air-conditioning system etc. within the spacecraft. Irradiated energy from the sun which is absorbed the spacecraft is also to be rejected to outer space by radiation. The tubes from the heat source carry the hot coolant that dumps the internally generated heat to the radiator. The extended surfaces of the radiator reject the heat to space by thermal radiation.

The technological difficulties involved in the manufacture of heat exchanger for space applications include fabrication, surface finish, surface coatings, selective coatings, etc. Time and expense are involved with all such applications. To create an environment similar to that in space is very expensive but essential for testing purpose.

1.2 PROBLEM STATEMENT

The main problem that has to overcome is to remove heat generated inside spacecraft. Thus, space radiator is needed to remove this unwanted heat at high efficiency. But, to simulate conditions of outer space where convection is not present is difficult and costly. The heat exchanger thus designed has to be tested at the surface of earth for its performance before deployment at outer space.

1.3 OBJECTIVE OF THE PROJECT

The objective of this project is to evaluate fin performance of a space radiator to remove heat generated for outer space application.

1.4 PROJECT SCOPE

Cooling of the heat generated sources inside the space craft is based on conventional design methods involving conduction and convection with variable gravitational force term. Heat rejection to outer space is the area of present work where radiation is the dominant single mode. Extended surfaces are advantageous for current situation for heat dissipation to outer space. Hence convection cannot be excluded in the testing of space radiator. The present analysis includes convection and irradiation terms. This method of approach helps to estimate its performance under actual working conditions.

1.5 SUMMARY

In this chapter, the problem statement, objective and scope of the project is discussed to recognize the problem occur, purpose and range to evaluate fin performance at outer space.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Advance from chapter 1, this chapter present the field of heat transfer, space radiator, dimensionless number, numerical approach and FORTRAN Software. The result in the previous research is discussed to obtain the information about method and parameter used to verify present result.

2.2 SPACE RADIATOR

Space radiator is a thermal radiator system use on an outer space vehicle, which must survive a long period of nonuse and then radiate large amounts of heat for a limited period of time.

Figure 2.1: International Space Station (ISS)

Source: NASA (2001)

2.2.1 Different Car Radiator and Space Radiator

Radiators are used for cooling internal combustion engines, chiefly in automobiles. They operate by passing a liquid coolant through the engine block, where it is heated, then through the radiator itself where it loses this heat to the atmosphere by convection and radiation. This coolant is usually water-based, but may also be oil. It's usual for the coolant flow to be pumped, also for a fan to blow air through the radiator.

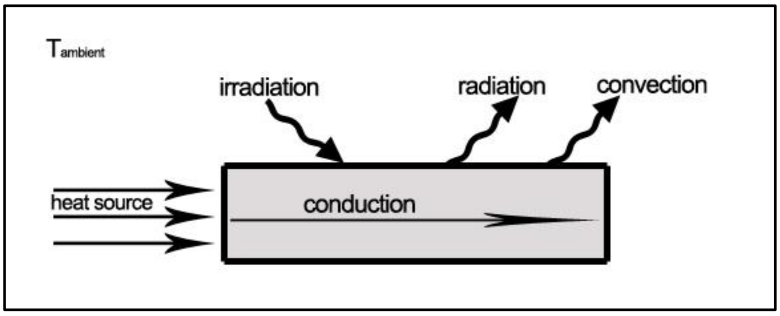

Figure 2.2: Block diagram for heat transfer component in car radiator (atmosphere condition)

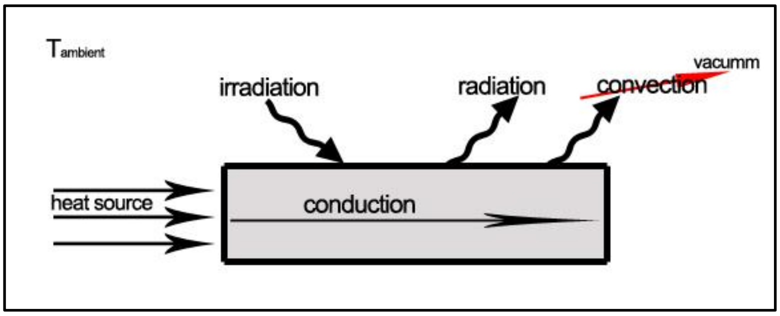

Figure 2.3: Block diagram for heat transfer component in space radiator (vacuum condition)

Source: Kumar et al. (1993)

A thermal radiator system is described for use on an outer space vehicle which must survive a long period of nonuse and then radiate large amounts of heat for a limited period of time. Space radiator has the same function with car radiator but in the outer space, heat can be transferred only by conduction, radiation and irradiation. Thus, radiation is the main parameter to know how efficient of the fin to remove heat.

2.2.2 Application of Space Radiator

There is a lot of heat generated inside the spacecraft such as air condition system, electronic and electrical equipment and human beings. Thus, that unwanted energy must be removed to maintain the equipment's temperature. Since no transferred medium in the outer space, convection heat transfer can't occur. It means, almost heat is transferred by radiation. The equipment can dump energy into space because any object at a reasonable temperature emits radiation. If its surroundings are colder than it is, it receives less radiation back than it radiates itself, and so it cools. This is just what a space radiator does. Nowadays, fin is famously used in radiator to remove unnecessary heat by evaluate surface area.

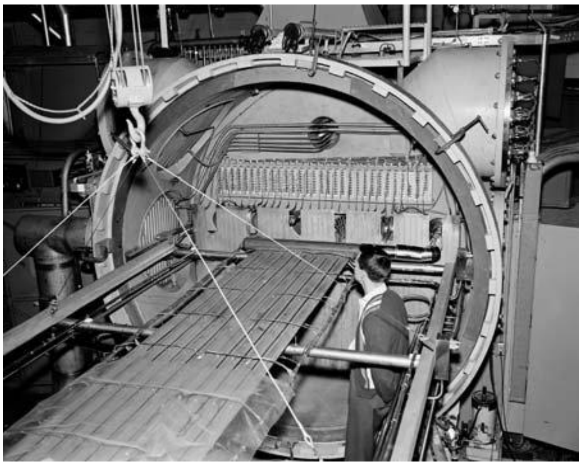

Figure 2.4: The International Space Station Radiator System

Source: NASA (2004)

2.2.3 Purpose of Thermal Control in Spacecraft

The space radiator has to control the operating temperature environment of spacecraft systems to maximize the efficiency of spacecraft equipment and to prevent from damage. There are some effect when the component inside spacecraft operate beyond their operating temperature where;

i. Most systems become less reliable when operated outside their design operating environment
ii. Propellant freezes
iii. Thermal cycling damage
iv. Instrument/antenna/camera alignment
v. Instrument requirements for very cold temperatures

Table 2.1: Typical spacecraft components temperatures

Component/ system	Operating temperature (°C)	Survival temperature (°C)
Digital electronics	0 to 50	-20 to 70
Analog electronics	0 to 40	-20 to 70
Batteries	10 to 20	0 to 35
IR detectors	-269 to -173	-269 to 35
Solid-state particle detectors	-35 to 0	-35 to 35
Momentum wheels	0 to 50	-20 to 70
Solar panels	-100 to 125	-100 to 125

Source: Pisacane, Vincent and Moore (1994)

2.3 DEFINITION OF FIN

Extended surface, in the forms of longitudinal or radial fins or spines are ubiquitous in applications where the need exits to enhance heat transfer between a surface and an adjacent fluid. Extended surface heat transfer is the study of high performance heat transfer components with respect to smaller weights, volumes, costs, accommodating shapes and of their behavior in a variety of thermal environments. In the design and construction of various types of heat transfer equipment, simple shapes such as cylinders, bars and plates are used to implement the flow of heat between sources and sink.

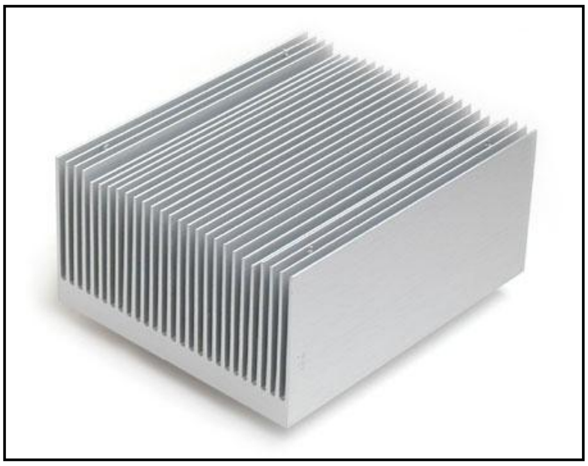

Figure 2.5: Arrangement of fin in forged fin

Source: Ixbtlabs (2010)

2.4 PREVIOUS RESEARCH

Extended surfaces (fins) are an effective and well established means of enhancing heat transfer between a primary surface and its environment. Practical applications of fins are numerous ranging from cooling of electronic equipment to heat rejection devices for the space vehicles.

The heat dissipation mechanism considered in most studies is either pure convection or pure radiation. In applications where fins operate in a free or natural convection environment, the contribution of radiation is equally significant, and therefore the design must allow for simultaneous convection and radiation. An example of such application is the stamped heat sink or extruded heat sink designed for cooling a transistor. Even if forced convection is employed for cooling, radiation can be significant if the operating temperatures are high as is the case with a finned regenerator. Cobble (1964) was perhaps the first to study the combined convection-radiation from a fin. He considered a horizontal circular pin fin and derived an approximate analytical solution. Experiment was conducted by Cobble to predict temperature distributions along the circular fin for aluminum and steel material. The temperature and fin efficiency was predicted by solving the nonlinear fin equation using a substitution developed by using the Gregory-Newton Forward Interpolation formula.

The temperature variation is expressed in Jacobian elliptic functions. The result is shown at Figure 2.6.

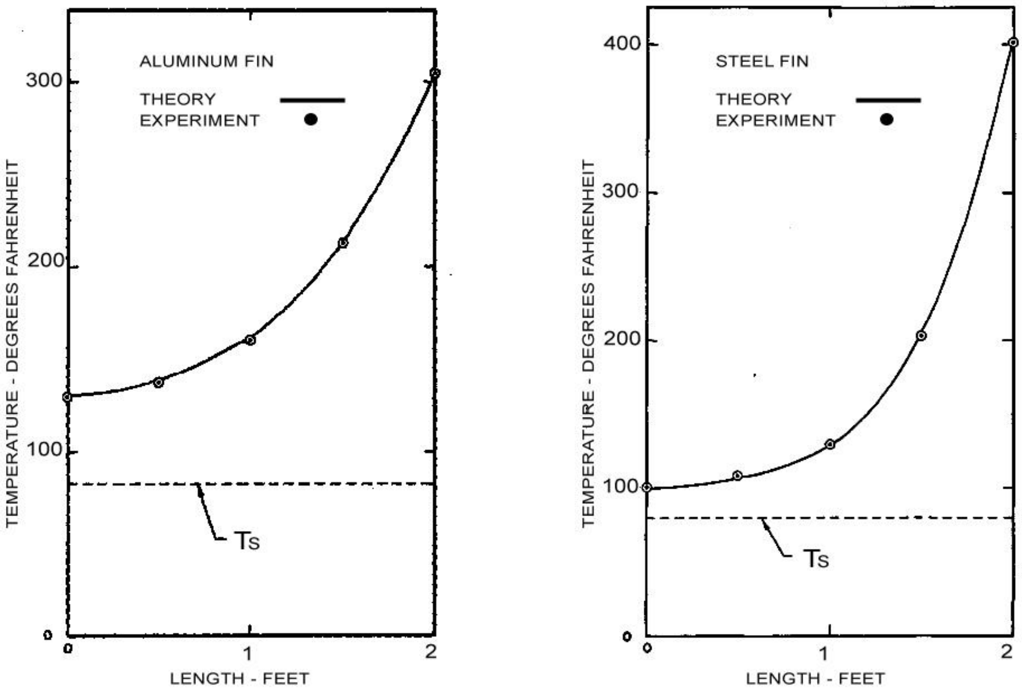

Figure 2.6: Temperature distributions for aluminum (left) and steel fin (right)

Source: Cobble (1964)

Aziz and Arlen (2009) show the effect of convection and radiation parameter to the heat loss from fin. Figure 2.7 shows how the temperature distribution in a fin of constant thermal conductivity with an insulated tip ($a = 0$, $N_{t1} = 0$, $N_{t2} = 0$) is affected by the variation of Bi characterizing the base convection process, the wall conduction resistance, and the contact resistance between the wall and the fin base.

To study the effect of varying the convection-conduction number N_C on the performance of the fin, the other variables were kept fixed at $a = 0$, $N_{t1} = 0$, $N_{t2} = 0$, $Bi = 1$, $N_R = 1$, $h_S = 0.2$. Figure 2.7 (left) shows the temperature distributions for $N_C = 1, 2, 3,$ and 4. As the surface convection gets stronger, the temperatures in the fin get increasingly depressed and the heat flow through the base of the fin increases but the efficiency decreases. The results are consistent with the well known performance characteristics of pure convective fins.